#5

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT:	RAMASUBRAMANIAN.	EXAMINER:	
SERIAL NO.:	09/919,050	GROUP:	2600
FILED:		CASE NO.:	CR00257M
TITLED:	METHOD AND SYSTEM FOR TIMING RECOVERY AND DELAY SPREAD ESTIMATION IN A COMMUNICATION SYSTEM		

Motorola, Inc.
Corporate Offices
1303 E. Algonquin Road
Schaumburg, IL 60196
October 9, 2002

Correspondence

Certificate of Transmission under 37 CFR 1.8

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on 10-10-02

Motorola, Inc. — 10-10-02

Name of applicant, assignee, or Registered Representative — Date

Signature

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OCT 10 2002
PETITIONS OFFICE

Box Non-Fee Amendment
Assistant Commissioner for Patents and Trademarks
Washington DC, 20231

[redacted]

Per our phone conversation on October 8th, 2002, I am requesting that the petition that was dismissed in the above-referenced application, be reconsidered under 37 CFR 1.10(e). As indicated in our phone conversation, all original documents were included with the original petition under 37 CFR 1.182

by:
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PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PROVISIONAL PATENT APPLICATION EXPRESS MAIL COVER LETTER

Express Mailing Date: December 29, 2000

Express Mail Label No.: EF263309519US

Applicant(s): RAMASUBRAMANIAN ET AL.

Docket No.: CR00257M

Entitled: METHOD AND SYSTEM FOR TIMING RECOVERY AND DELAY SPREAD ESTIMATION IN A COMMUNICATION SYSTEM

Motorola, Inc.
Corporate Offices
1303 E. Algonquin Road
Schaumburg, IL 60196
December 29, 2000

To: Assistant Commissioner for Patents
Box Provisional Patent Application
Washington, D.C. 20231

Dear Sir:

Transmitted by Express Mail herewith for filing under 37 CFR 1.53 (c) for the above identified patent application are the following Provisional Patent Application documents:

X Provisional Patent Application Cover Sheet (1 page(s))

X New Provisional Patent Application; including 14 pages of specification (including 4 pages of claims and 1 page of abstract), and 7 sheets of drawings.

X Return Receipt Postcard

I certify that this letter and all of the above-referenced papers are being deposited with the United States Postal Service, postage prepaid, as US Express Mail on the above indicated Express Mailing Date in an envelope having the above indicated Express Mailing Label No. and addressed to:

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Signature Date: 12/29/00

Signature:

Printed Name: JAMES E . GAUGER
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Rev. 8/18/98 phm

PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53 (c).

Docket Number	CR00257M	Type a plus sign (+) inside this box -->	

INVENTOR(s)/APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
RAMASUBRAMANIAN	KARTHIK		Schaumburg, IL
BAUM	KEVIN	L.	Rolling Meadows, IL

TITLE OF THE INVENTION (280 characters max)

METHOD AND SYSTEM FOR TIMING RECOVERY AND DELAY SPREAD ESTIMATION IN A COMMUNICATION SYSTEM

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STATE	ILLINOIS	ZIP CODE	60196	COUNTRY	USA

ENCLOSED APPLICATION PARTS *(check all that apply)*

[X] Specification+Clms	*Number of Pages*	14	[ ] Small Entity Statement	
[X] Drawing(s)	*Number of Sheets*	7	[ ] Other (specify)	

METHOD OF PAYMENT *(check one)*

[ ] A check or money order is enclosed to cover the Provisional filing fees

[X] The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 13-4772
Two duplicate copies of this sheet enclosed.

PROVISIONAL FILING FEE AMOUNT ($) 150.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[X] No.

[ ] Yes, the name of the U.S. Government agency and the Government contract number are: ______

Respectfully submitted,

SIGNATURE ______ **Date** 12/29/00

TYPED or PRINTED NAME JAMES E. GAUGER **REGISTRATION NO.** *(if appropriate)* 38,154

[ ] Additional inventors are being named on separately numbered sheets attached hereto

PROVISIONAL APPLICATION FILING ONLY

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Docket No.:	CR00257M	Filed:	12/29/2000
Applicant:	Ramasubramanian et al	Examiner:	TBA
Serial No.:	TBA	Group No.:	TBA
Batch No.:	TBA		
Entitled:	METHOD AND SYSTEM FOR TIMING RECOVERY AND DELAY SPREAD ESTIMATION IN A COMMUNICATION SYSTEM		
DDF/kgk	Paid by Deposit Account $150.00 =$150.00 TOTAL		

All items with an "X" are included in Express Mail EF263309519US package.

		Description
1.	X	Provisional Patent Application Transmittal (1 page +1copy)
2.	X	Provisional Application Cover Sheet (1 page + 1 copy)
3.	X	_14_ pages of Specification Claims and Abstract
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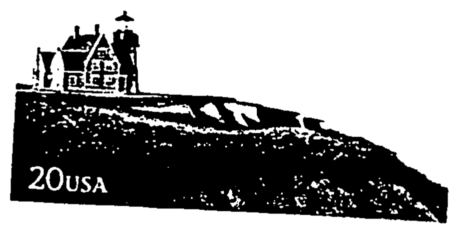

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EF 263309519 US

METHOD AND SYSTEM FOR TIMING RECOVERY AND DELAY SPREAD ESTIMATION IN A COMMUNICATION SYSTEM

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to communication systems, and in particular, to a new timing recovery and delay-spread estimation scheme for communication systems that employ cyclically extended symbols.

BACKGROUND OF THE INVENTION

Timing recovery in communication systems is related to the process of identifying symbol boundaries in a received signal, so that each symbol can be windowed and processed separately so that its value can be determined. In some communication systems such as OFDM (other examples include IFDMA, Single Carrier with cyclic extension), a guard interval is inserted between successive symbols to overcome inter-symbol interference (ISI) caused by multipath delay-spread in the communication channel. Usually each symbol is cyclically extended with a prefix and/or a postfix to cover the guard interval. The cyclic extension absorbs the delay-spread and thus keeps the data portion of the symbol free of ISI. When the channel delay-spread is less than the duration of the cyclic extension, only a portion of the cyclic extension is corrupted while the rest remains ISI-free. This creates ambiguity in the timing recovery process because there is more than one possible position of the *sampling-window* for obtaining an ISI-free representation of the symbol.

FIG. 1 shows an exemplary OFDM symbol with cyclic prefix partly corrupted by ISI and the range of ISI-free sampling-window positions available for that symbol.

Although known methods for timing recovery in OFDM systems are adequate and beneficial in many situations, they present several shortcomings. In a method proposed by Jan-Jaap van de Beek *et al.*, "ML Estimation of Time and Frequency Offset In OFDM Systems", IEEE Transactions on Signal Processing, Vol. 45, No. 7, July 1997 (hereinafter

"Jan-Jaap van de Beek "), the cyclic extension is used to identify the best sampling position. Unfortunately, this method is optimized and well suited only for a single-ray channel. As a consequence, in a multipath-fading channel, the sampling position picked by this method may not be free of ISI and it can waver depending on which of the multipath rays is the strongest at a particular time. These shortcomings in a multipath-fading channel are critical, considering that one of the purposes behind OFDM is to reduce the effects of multipath fading.

In another method proposed by T.M. Schmidl *et al.*, "Low-Overhead, Low-Complexity [Burst] Synchronization for OFDM", Proceedings of ICC 1996, vol. 3, pp. 1301-1306 (hereinafter "Schmidl"), a special training symbol is used to estimate a sampling position. The disadvantage of this method is that the sampling position picked by this method could jump about within a set of valid positions, leading to jitter in the timing estimates. The jitter makes it difficult to use averaging, e.g., a phase locked loop (PLL), to obtain a steady sampling position. Another disadvantage with this method is that the timing estimate is based on the training symbol alone and there is no averaging over the fading process. This creates problems in a fast fading scenario where the instantaneous delay profile at the training symbol could be significantly different from the true delay profile.

Both of the above-mentioned methods for timing recovery in OFDM systems involve finding the correlation between two symmetric portions of the OFDM symbol. In the Jan-Jaap van de Beek method, the symmetry between the cyclic extension and the data portion of the OFDM symbol is exploited, whereas in the Schmidl method, the symmetry between the first and second halves of a special training symbol is exploited.

In addition, the Jan-Jaap van de Beek and Schmidl methods both employ a sliding sum that adds up consecutive correlation values over the window of symmetry. For example, in the Jan-Jaap van de Beek method, consecutive correlation values are summed together over a window of length *L*, where *L* is the length of the cyclic extension. Consequently, the correlation is summed over the length of the entire cyclic extension, regardless of the fact that part of it could be corrupted by ISI. This degrades the correlator output by adding incoherent correlation values to the coherent ones. It can also

result in a loss of information regarding how much of the cyclic extension is corrupted, or in other words, the delay-spread.

Accordingly, there is a need for an improved method of timing recovery and delay-spread estimation in communication systems employing cyclic extension.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an exemplary OFDM symbol;

FIG. 2 is a flowchart illustrating a method of performing timing recovery in accordance with the invention;

FIG. 3 is a block diagram of an exemplary receiver in accordance with the invention;

FIG. 4 is a set of graphs showing an exemplary comparison between the ensemble correlation function of the present invention and the correlation functions of two known methods of timing recovery for OFDM;

FIG. 5 is a set of histograms showing an exemplary comparison between the timing recovery method of present invention and two known methods of timing recovery for OFDM;

FIG. 6 is a flowchart of a method for estimating channel delay-spread in accordance with the present invention; and

FIG. 7 is a flowchart of a method of processing an information signal based on an ensemble correlation metric in accordance with the invention.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENT(S)

The present invention provides a timing recovery scheme that demarcates a complete range of ISI-free sampling positions available in an OFDM symbol. The invention also features a method for estimating the multipath delay-spread in the channel. The delay-spread estimate provides a receiver valuable information about the nature of the channel. The receiver can use this information, for example, to adjust the frequency-domain channel interpolation filter bandwidth in order to improve performance for the given channel condition.

The invention uses the correlation between the cyclic extension and the data part of the OFDM symbol to estimate the timing. However, it has key differences from known techniques in the way the correlation is computed and used to estimate timing. For example, according to an aspect of the invention, a correlation function provides better delay-spread and timing information by not combining together consecutive correlation values over the entire length of the cyclic extension. Instead, the function separately maintains the correlation value for each sample position within the OFDM symbol duration and combines the correlation values for identical sample positions over an ensemble of OFDM symbols.

In this manner, the invention can provide an improved method for estimating the symbol timing from the received OFDM signal. Each sample position in the OFDM symbol can be inspected separately. Consequently, the method can provide a steady, jitter-free estimate of the symbol timing for a variety of channel conditions. In addition, the method can average the correlation function over a large number of symbols to provide robustness to fast fading, i.e., to limit the impact of instantaneous fades on performance.

The correlation function retains delay-spread and timing information by not combining consecutive correlation values together over the entire length of the cyclic extension. Instead, it separately maintains the correlation value for each sample position within the OFDM symbol duration and combines the correlation values for identical sample positions over an ensemble of OFDM symbols. Identical sample positions in successive OFDM symbols are

separated by $N+L$ samples, N being the fast Fourier transform (FFT) size and L being the length of the cyclic extension, where N and L are integers. Therefore, the correlation function sums correlation values spaced by $N+L$ positions. This sum is done over an ensemble of, for example, M OFDM symbols and then normalized, where M is an integer. If r denotes the received signal sequence, this "ensemble correlation function" can be expressed in equation form as follows:

$$\rho(k)=\frac{\left|\sum_{m=0}^{M-1} r^{*}(k+m(N+L))r(k+m(N+L)+N)\right|}{\sqrt{\sum_{m=0}^{M-1}\left|r(k+m(N+L))\right|^{2}}\sqrt{\sum_{m=0}^{M-1}\left|r(k+m(N+L)+N)\right|^{2}}}$$

$0 \le k < N+L$

(1)

Since the ensemble correlation function computes the correlation coefficient separately for each sample position in the OFDM symbol duration, it gives information about what portion of the cyclic extension is corrupted due to channel delay-spread. This makes it possible to estimate the delay-spread and also to identify and demarcate a range of ISI-free sampling points available. In a single-ray channel, where there is no delay-spread, the ensemble correlation function has a plateau of width L, indicating that every sample of the cyclic extension matches the corresponding sample of the data portion of the symbol. In a multipath channel, the width of the plateau reduces depending on the extent of delay-spread D in the channel.

FIG. 2 is a flowchart 20 of an exemplary method for using the ensemble correlation function of Eq. (1) to estimate OFDM symbol timing. In step 22, the ensemble correlation function is computed over a plurality of OFDM symbols according to Eq. (1). Next, in step 24, the output of the ensemble correlation function is post-processed as follows. First, a 3-tap or 5-tap median filter can be used to remove any sharp glitches in the correlation function, while still retaining the distinct nature of the plateau and its sharp edges.

Next, in step 26, the peak value, p of the correlation function is found and a threshold value, t is determined as a function of the peak as $t = p-\alpha(1-p)$, where $\alpha > 0$ is a design parameter.

In step 28, the first and last points where the correlation function crosses the threshold are determined and the region in between these two points is declared the ISI-free sampling region. The width of this region W is subtracted from the total length of the cyclic extension to obtain an estimate of the channel delay-spread.

$$\hat{D} = L - W \tag{2}$$

In the initial acquisition stage, the plateau may be split between the two ends of the ensemble correlation function. In other words, the plateau starts at a point close to $k = N+L$, and wraps back around to $k = 0$. One way to alleviate this wrap-around is to circularly shift the correlation function such that the peak value p is positioned at the center, i.e., at $k = (N+L)/2$. This ensures that the plateau lies approximately at the center of the correlation function. An equivalent adjustment can also be made to the timing estimate as well.

In a tracking mode, the ensemble correlation function is computed and processed as above for every group of M OFDM symbols received. The estimated start and end points of the plateau are tracked using two phase locked loops (PLLs). This yields a steady estimate of the delay spread and the ISI-free sampling region.

The ensemble function of Eq. (1) is one example of a correlation function usable with the present invention. Other forms of ensemble functions can be used, for example, those having different normalization functions or denominator computations than those disclosed herein.

FIG. 3 is a block diagram of an exemplary receiver 50 in accordance with another embodiment of the invention. The receiver 50 can be included in a communication system, such as a cellular and/or paging system, using an OFDM scheme or the like. The receiver 50 includes a timing recovery/delay-spread estimator 52, that includes a correlator 54, a filter 56, a peak (max) detector 58, a comparator 60, a pair of PLLs 62-64, and a subtractor 66.

The correlator 54 receives digital samples representing OFDM symbols and computes the ensemble correlation function in accordance with Eq. (1). The output of the correlator 54 is filtered by the filter 56, which can be any suitable digital filter, including the either of the median filters discussed above in connection with FIG. 2. The peak detector 58 determines the peak value and provides as output to the comparator the threshold value described above in connection with FIG. 2.

The comparator 60 compares the filtered outputs of the ensemble correlation function to the threshold value to determine crossing points. The PLLs 62-64 can be any suitable PLL, digital or analog, for tracking the threshold crossings.

The subtractor 66 outputs the delay-spread estimation by subtracting the width of the sampling region from the length of the cyclic extension of the OFDM symbol.

The architecture of the timing recovery/delay-spread estimator (TRDSE) 52 is shown as an example. The structure of the TRDSE 52 can include any suitable combination of hardware and/or software components for performing the functions of the components 54-66 described herein.

FIG. 4 shows a plot 84 of the ensemble correlation function used by the present invention and compares it to the correlation functions used by the known methods presented by Jan-Jaap van de Beek 80 and Schmidl 82. Two different channel conditions are shown in the columns of the plot – one where the channel is ideal with no delay-spread (left column) and another where the channel is noisy and has some delay-spread (right column). The number of OFDM symbols used in computing the ensemble correlation function shown was $M = 200$. It can be observed from the FIG. 4 that the method of Jan-Jaap van de Beek provides a single peak and does not give any delay-spread information. This peak does not always occur at an ISI-free sampling position. The method of Schmidl provides a plateau, but this plateau is not "well-marked" and is therefore difficult to identify and demarcate.

In contrast, the method of the present invention provides a distinct plateau, which clearly demarcates a range of ISI-free sampling positions available. Thus, the timing information extracted by the present invention is superior compared to the previous methods.

FIG. 4 also illustrates that the total height of the plateau is proportional to the total signal power and the height of each individual step that leads to the plateau is proportional to the power of a corresponding multipath ray.

FIG. 5 shows a histogram 104 of the timing estimate generated by the method of the present invention as compared with the known methods of Jan-Jaap van de Beek 100 and Schmidl 102. The parameters used to generate the histogram were $N = 1024$, $L = 256$, $M = 200$, $\alpha = 0.35$. The OFDM symbol rate was 20 kHz. The channel was a 4-ray channel with a delay span equal to one-half the length of the cyclic extension. An exponentially decaying power delay profile was used with the last ray having a power 3 dB below the first ray. Each ray was faded at a Doppler frequency of 300 Hz, which corresponds to a vehicle speed of 58 mph at a carrier frequency of 3.5 GHz. The signal-to-noise ratio (SNR) was 10 dB.

It can be observed from the histogram plots 100-102 that the Jan-Jaap van de Beek method can frequently pick sampling positions outside the valid sampling region. Thus, the timing estimate from this method is not free of ISI.

The Schmidl method picks sampling positions within the valid sampling region most of the time, but these estimates jump around within the valid sampling region leading to jitter in the timing estimate.

In contrast, the method of the present invention provides an accurate estimate of the start and end of the valid sampling region. Any particular point within this region can then be fixed as the estimated sampling position. This method is much more reliable than previous methods in the sense that the timing estimate is ISI-free for a variety of channel conditions.

Furthermore, since this method provides an estimate of the entire valid sampling region, it is possible to sample the signal using more than one sampling window and combine the outputs appropriately to improve performance. Also, the delay-spread information provided by this method can be used to adjust the frequency-domain channel interpolation filter bandwidth to provide optimum performance. These techniques can yield up to 1 dB improvement in performance.

While specific embodiments of the present invention have been shown and described, it will apparent to those skilled in the art that the disclosed invention may be modified in numerous ways and may assume many embodiments other than those specifically set out and described above. Accordingly, the scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

CLAIMS

1. A method for timing recovery in an orthogonal frequency division multiplexed (OFDM) system, comprising:

computing an ensemble correlation function over a plurality of OFDM symbols; and

comparing the output of the ensemble correlation function to a threshold to define a sampling region within the duration of an OFDM symbol.

2. The method of claim 1, wherein the sampling region defines the boundaries of the OFDM symbol.

3. The method of claim 1, further comprising:

filtering the output of the ensemble correlation function.

4. The method of claim 3, further comprising:

using a median filter to filter the output of the ensemble correlation functions.

5. The method of claim 1, further comprising:

determining a peak value included in the output of the ensemble correlation function.

6. The method of claim 5, further comprising:

determining the threshold as a function of the peak value.

7. The method of claim 1, wherein the threshold crossing points of the ensemble correlating function output define the sampling region.

8. A system, comprising:

a correlator for computing an ensemble correlation function over a plurality of received OFDM symbols; and

a comparator, operatively coupled to the correlator, for comparing the output of the ensemble correlation function to a threshold to define a sampling region within the duration of an OFDM symbol.

9. The system of claim 8, further comprising:

a filter, operatively coupled to the correlator, for filtering the output of the ensemble correlation function.

10. The system of claim 8, further comprising:

a max detector, operatively coupled to the filter, for determining a peak value included in the output of the ensemble correlation function.

11. The system of claim 8, for use in a receiver.

12. The system of claim 11, wherein the receiver is wireless.

13. The system of claim 8, further comprising:

at least one phase locked loop for tracking the edges of the sampling region.

14. A method for estimating delay spread in an orthogonal frequency division multiplexed (OFDM) system, comprising:

computing an ensemble correlation function over a plurality of OFDM symbols, each of the OFDM symbols including a cyclic extension having a length;

comparing the output of the ensemble correlation function to a threshold to define a sampling region within the duration of an OFDM symbol; and

subtracting a width of the sampling region from the length of the cyclic extension of the OFDM symbol to obtain an estimate of the delay spread.

15. The method of claim 14, further comprising:

filtering the output of the ensemble correlation function.

16. The method of claim 15, further comprising:

using a median filter to filter the output of the ensemble correlation functions.

17. The method of claim 14, further comprising:

determining a peak value included in the output of the ensemble correlation function.

18. The method of claim 17, further comprising:

determining the threshold as a function of the peak value.

19. The method of claim 14, wherein the threshold crossing points of the ensemble correlating function output define the sampling region.

20. A system for estimating delay spread in an orthogonal frequency division multiplexed (OFDM) system, comprising:

a correlator for computing an ensemble correlation function over a plurality of OFDM symbols, each of the OFDM symbols including a cyclic extension having a length;

a comparator, operatively coupled to the correlator, for comparing the output of the ensemble correlation function to a threshold to define a sampling region within the duration of an OFDM symbol; and

a subtractor, operatively coupled to the comparator, for subtracting a width of the sampling region from the length of the cyclic extension of the OFDM symbol to obtain an estimate of the delay spread.

21. The system of claim 20, further comprising:

a filter, operatively coupled to the correlator, for filtering the output of the ensemble correlation function.

22. The system of claim 20, further comprising:

a max detector, operatively coupled to the filter, for determining a peak value included in the output of the ensemble correlation function.

23. The system of claim 20, for use in a receiver.

24. The system of claim 23, wherein the receiver is wireless.

METHOD AND SYSTEM FOR TIMING RECOVERY AND DELAY SPREAD ESTIMATION IN A COMMUNICATION SYSTEM

ABSTRACT OF THE DISCLOSURE

A timing recovery scheme demarcates a complete range of inter-symbol interference free (ISI-free) sampling points available in an orthogonal frequency division multiplex (OFDM) symbol. The timing recovery scheme computes a correlation between the cyclic extension and the data part of OFDM symbols to estimate timing. The correlation function retains delay-spread and timing information by not combining consecutive correlation values together. Instead, the function separately maintains the correlation value for each sample position within the OFDM symbol duration and combines the correlation values for identical sample positions over an ensemble of OFDM symbols. In this manner, the scheme not only provides timing estimates, but can also provide estimates of the multipath delay-spread in a channel. The delay-spread estimates provide valuable information about the nature of the channel. A receiver can use this information, for example, to adjust the frequency-domain channel interpolation filter bandwidth in order to improve performance for the given channel condition.

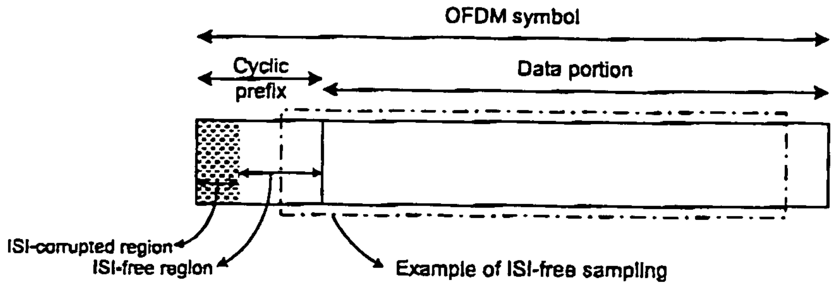
OFDM symbol
Cyclic prefix
Data portion
ISI-corrupted region
ISI-free region
Example of ISI-free sampling

FIG. 1

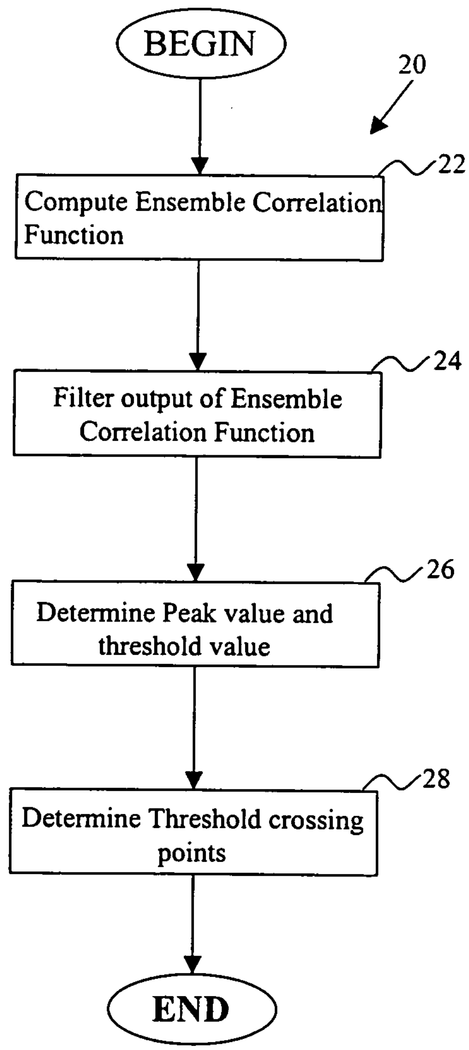
BEGIN
20
22
Compute Ensemble Correlation Function
24
Filter output of Ensemble Correlation Function
26
Determine Peak value and threshold value
28
Determine Threshold crossing points
END

FIG. 2

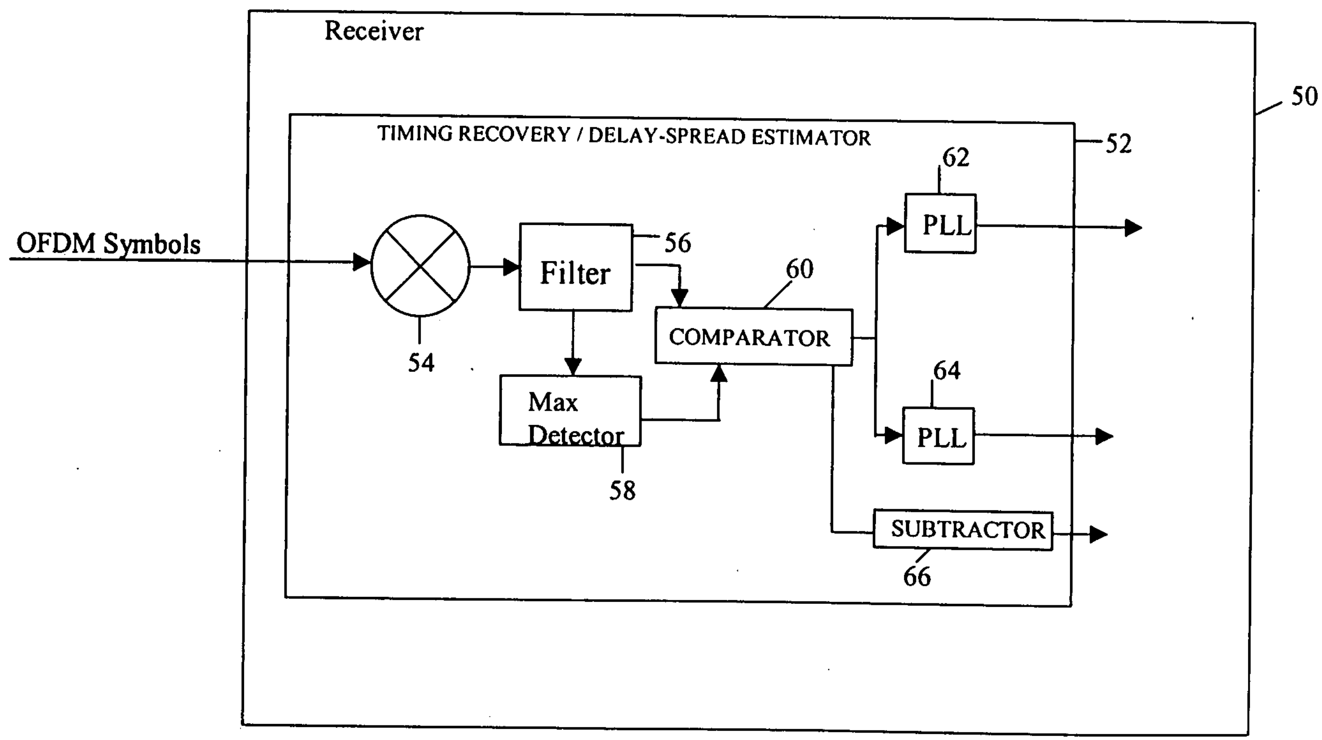
Receiver
50
TIMING RECOVERY / DELAY-SPREAD ESTIMATOR
52
OFDM Symbols
54
Filter
56
Max
Detector
58
COMPARATOR
60
PLL
62
PLL
64
SUBTRACTOR
66

FIG. 3

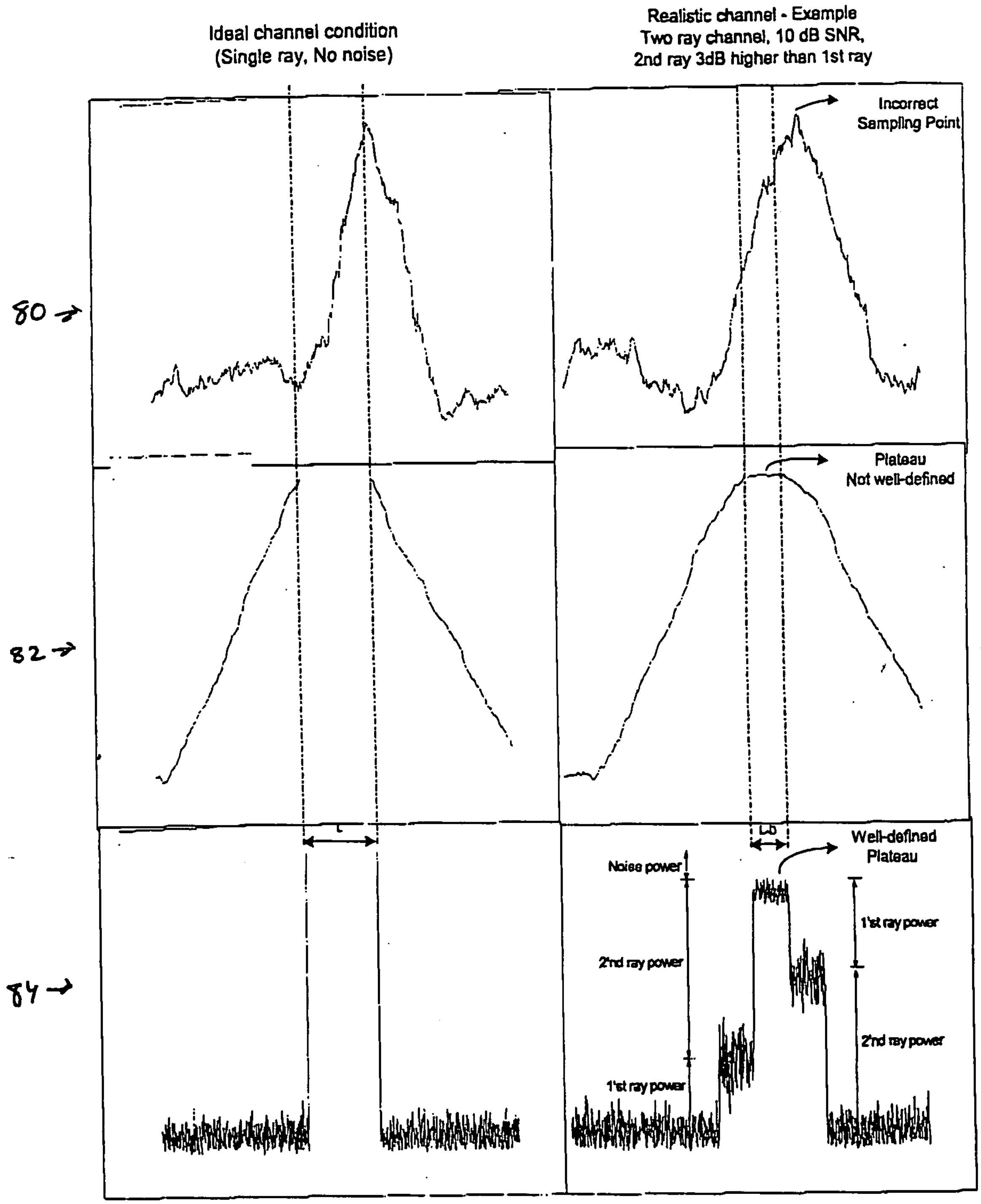
Ideal channel condition
(Single ray, No noise)
Realistic channel - Example
Two ray channel, 10 dB SNR,
2nd ray 3dB higher than 1st ray
Incorrect
Sampling Point
Plateau
Not well-defined
Well-defined
Plateau
Noise power
2'nd ray power
1'st ray power
1'st ray power
2'nd ray power
80
82
84

FIG. 4

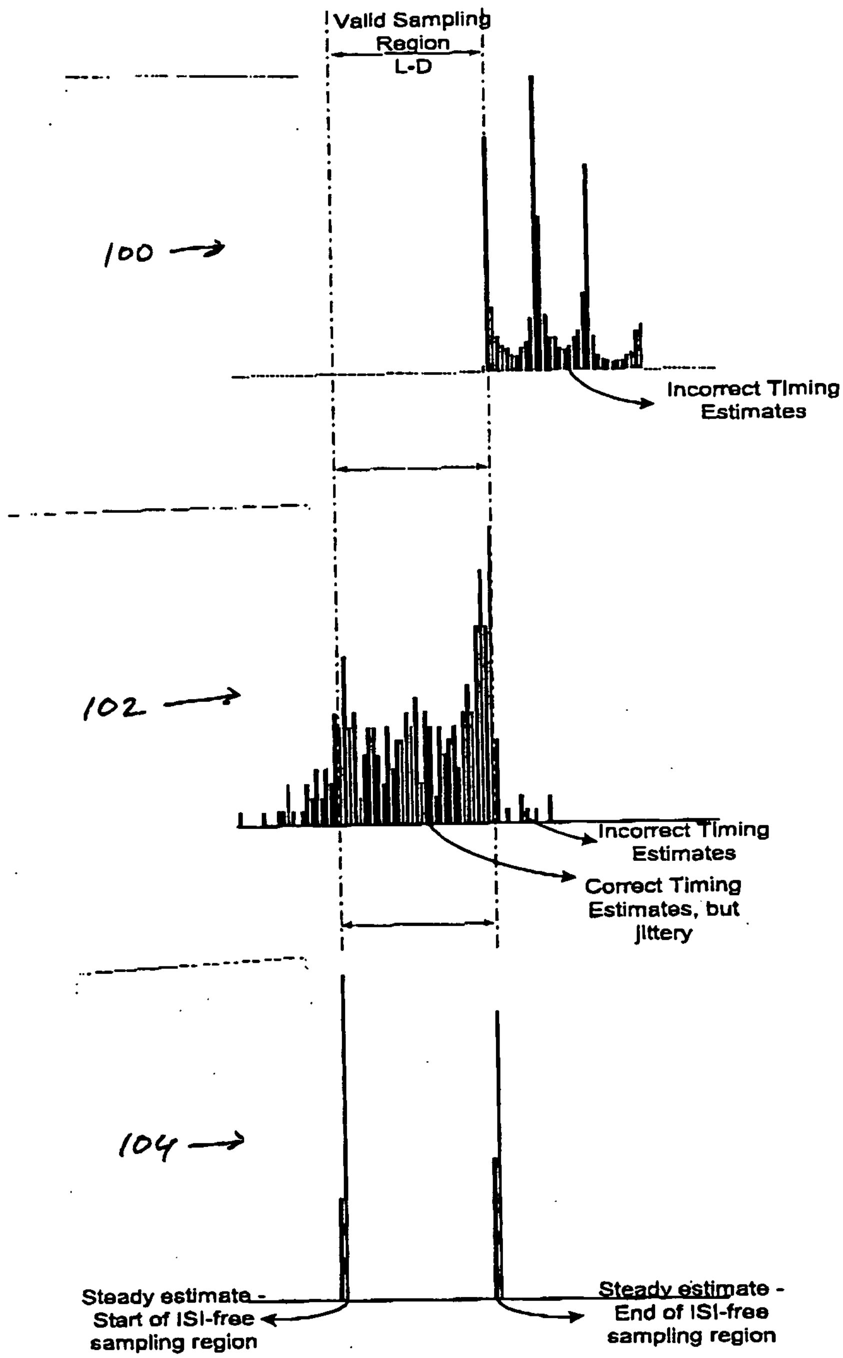
Valid Sampling Region
L-D
100
Incorrect Timing Estimates
102
Incorrect Timing Estimates
Correct Timing Estimates, but jittery
104
Steady estimate - Start of ISI-free sampling region
Steady estimate - End of ISI-free sampling region

FIG. 5

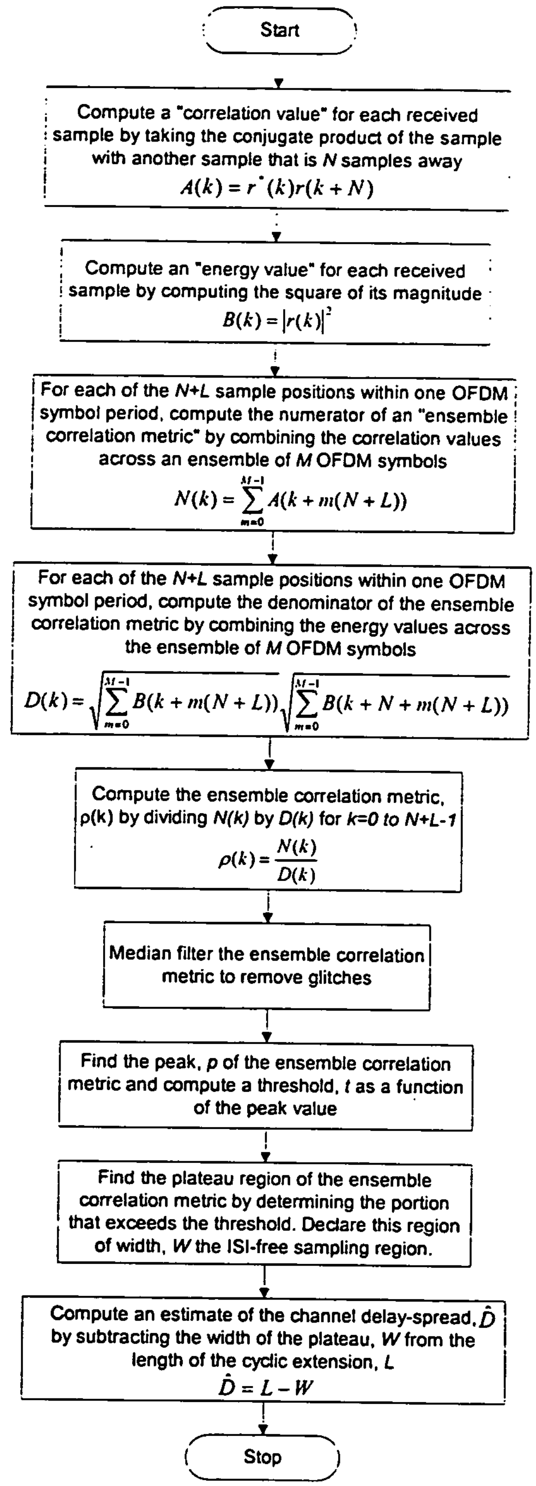
Start
Compute a "correlation value" for each received sample by taking the conjugate product of the sample with another sample that is N samples away
$A(k) = r^*(k)r(k+N)$
Compute an "energy value" for each received sample by computing the square of its magnitude
$B(k) = |r(k)|^2$
For each of the N+L sample positions within one OFDM symbol period, compute the numerator of an "ensemble correlation metric" by combining the correlation values across an ensemble of M OFDM symbols
$N(k) = \sum_{m=0}^{M-1} A(k + m(N+L))$
For each of the N+L sample positions within one OFDM symbol period, compute the denominator of the ensemble correlation metric by combining the energy values across the ensemble of M OFDM symbols
$D(k) = \sqrt{\sum_{m=0}^{M-1} B(k + m(N+L))}\sqrt{\sum_{m=0}^{M-1} B(k + N + m(N+L))}$
Compute the ensemble correlation metric, ρ(k) by dividing N(k) by D(k) for k=0 to N+L-1
$\rho(k) = \frac{N(k)}{D(k)}$
Median filter the ensemble correlation metric to remove glitches
Find the peak, p of the ensemble correlation metric and compute a threshold, t as a function of the peak value
Find the plateau region of the ensemble correlation metric by determining the portion that exceeds the threshold. Declare this region of width, W the ISI-free sampling region.
Compute an estimate of the channel delay-spread, $\hat{D}$ by subtracting the width of the plateau, W from the length of the cyclic extension, L
$\hat{D} = L - W$
Stop

FIG. 6

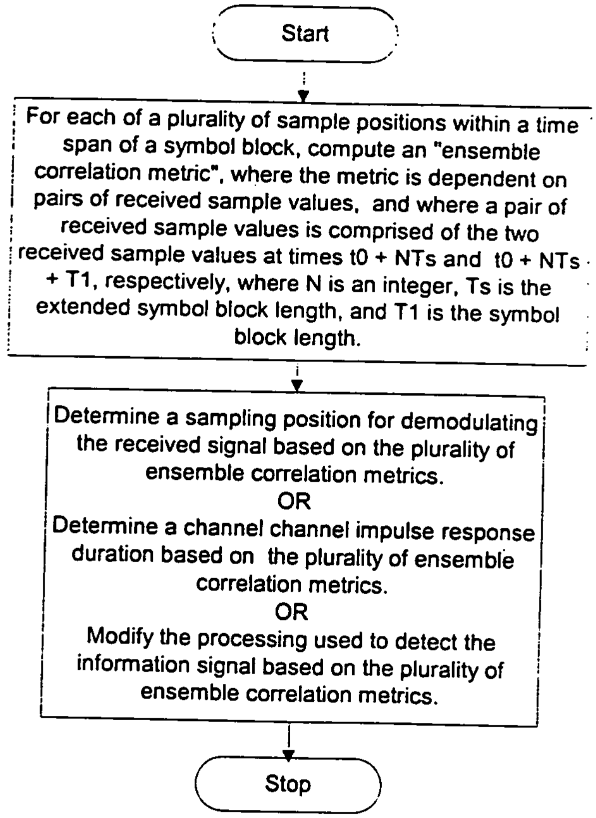
Start
For each of a plurality of sample positions within a time span of a symbol block, compute an "ensemble correlation metric", where the metric is dependent on pairs of received sample values, and where a pair of received sample values is comprised of the two received sample values at times t0 + NTs and t0 + NTs + T1, respectively, where N is an integer, Ts is the extended symbol block length, and T1 is the symbol block length.
Determine a sampling position for demodulating the received signal based on the plurality of ensemble correlation metrics.
OR
Determine a channel channel impulse response duration based on the plurality of ensemble correlation metrics.
OR
Modify the processing used to detect the information signal based on the plurality of ensemble correlation metrics.
Stop

FIG. 7